

ARTHROPODS ATTRACTED TO LUMINOUS FUNGI

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Some fungi emit light. Luminescence may be present in mycelia [e.g. a number of *Mycena* species (Wassink 1978)] or in both mycelia and fruiting bodies [e.g. North American populations of *Panellus* (= *Panus*) *stypticus*, Buller 1924]. Lights have been described as blue, white, or green depending on the species (Buller 1924, Wassink 1978). Emission intensities vary considerably. In the forests of Borneo *Mycena* (= *Poromyцена*) *manipularis* are visible at ca. 40 meters (Zahl 1971). An Australian species¹ "pours forth its emerald green light" with sufficient intensity to read by (Lauterer 1900 in Buller 1924). North American forms, such as examined here, tend to be dimmer. The eye often requires several minutes of dark adaptation before their glows become visible.

The receiver(s) toward which fungi direct their luminous signals are unknown. Lights have been supposed to lure spore dispersing insects (Ewart 1906), but such an argument fails to account for mycelial lights (Ramsbottom 1953). There has apparently been no conjecture on the benefits mycelia accrue by glowing. The different environments of mycelia and fruiting bodies make it questionable whether their lights are directed at identical receivers or even serve similar functions.

Until this time any proposed reactions of animals to fungal lights have been speculative. I here present evidence that certain arthropods are more likely to be captured in traps baited with light-emitting mycelia and fruiting bodies than in controls containing fungus-free substrate or dead and dark specimens of luminous species. Several possible interactions between fungi and attracted arthropods are discussed.

¹Described as *Panus incandescens*, a name of doubtful taxonomic value (see Wassink 1978).

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METHODS

Test tubes (10 × 75 mm) were covered with Tack Trap®, a sticky trapping compound, and capped with a cork. Luminous twigs, conifer needles and leaf fragments, covered with mycelia of a *Mycena* sp., were put into 31 such tubes. An identical number of control tubes contained similar but nonluminous forest litter. Tubes with glowing fungi were placed as closely as possible to the original position of their contents (note that mycelia are most abundant deep in litter, but traps were placed on the litter surface). Controls were set ca. 80 mm to the side. Glass screw top vials (14 × 40 mm) were also coated with Tack Trap®. From 3–6 fruiting bodies of the luminous mushroom *Dictyopanus pusillus* were put into 72 such vials. An identical number of controls contained 3–6 *D. pusillus*, killed and rendered nonluminous by bathing in alcohol. Luminous and control vials were alternately placed, ca. 80 mm apart, on and by rotting logs on which *D. pusillus* had been found. Traps were put out at night, gathered the following morning, and arthropods stuck on their surfaces removed.

All specimens were captured during August in Alachua County, Florida.

RESULTS

More arthropods were captured on traps baited with glowing fungal mycelia (*Mycena* sp.) and luminous fruiting bodies (*D. pusillus*) than their respective controls ($\chi^2 = 10.14$, $p < .001$; $\chi^2 = 6.41$, $p < .01$, see Table 1). Taxa significantly more abundant on luminous traps in the summed samples are Collembola ($\chi^2 = 12.81$, $p < .001$), and Diptera ($\chi^2 = 5.54$, $p < .025$). It is of interest that Collembola are not attracted to the bioluminescence of a sedentary luminous predator, larvae of the fungus gnat *Orfelia fultoni* (Sivinski 1982). Predators, i.e. spiders, ants, earwigs occur in a luminous:dark ratio that borders on significance ($\chi^2 = 3.76$, $p < .10$). Groups captured in statistically indistinguishable numbers on luminous and control traps are Isopods ($\chi^2 = 0.78$, $p > .25$) and Amphipods ($\chi^2 = 0.59$, $p > .25$). An unusual set of captures is the 5 crickets, *Eunemobius carolinus*, taken only with luminous mycelia.

Table 1. The numbers of Arthropods captured on traps containing luminous mycelia (*Mycena* sp.), luminous fruiting bodies (*Dictyopanus pusillus*), and their respective controls.

	<i>Mycena</i> sp.	Control	<i>D.</i> <i>pusillus</i>	Control	Summed Fungi	Summed Control
Collembola	22	8	31	14	53	22
Isotomidae/ Entomobryidae	21	8	12	7	32	11
Sminthuridae	1	0	19	7	20	7
Diptera	8	2	11	5	19	7
Phoridae	2	1	7	2	8	3
Sphaeroceridae	0	0	1	0	1	0
Cecidomyiidae	5	0	2	3	7	3
Ceratopogonidae	1	0	0	0	1	0
Psychodidae	0	1	0	0	0	1
Mycetophilidae	0	0	1	0	1	0
Predators	12	4	17	12	29	16
Araneida	3	1	7	4	10	5
Formicidae	9	1	9	8	18	9
Carabidae	0	1	0	0	0	1
Dermaptera	0	0	1	0	1	0
Hymenoptera	3	1	1	2	4	3
Isopods	32	29	37	30	69	59
Amphipods	0	1	9	7	9	8
Acari	0	1	1	0	1	1
Orthoptera	8	1	2	4	10	5
Gryllidae	5	0	0	0	5	0
Blattellidae	3	1	2	4	5	5
Cicadellidae	1	0	1	0	2	0
Thysanoptera	0	0	1	1	1	1
Unidentified	0	2	2	3	2	5
All Arthropods	86	49	113	78	199	127

DISCUSSION

Attraction of insects to fungal lights does not demonstrate that luring arthropods is the function of the bioluminescence. With this caveat in mind, note that an acceleration in the rate of certain fungus/insect interactions even as an effect of a bioluminescent signal is apt to influence the evolution of luminous fungi. In particular, the argument that fungal lights are functionless, and by implication harmless by-products of metabolism, loses force (see also Lloyd 1977). Bearing a light near arthropods is unlikely to be selectively neutral (for counterexamples, see Buller 1924; Prosser and Brown 1961).

Some possible functions of fungal glows become more plausible with, or fail to find support in, the presented data. Both are discussed below.²

Attraction of spore dispersers: Stinkhorn fungi (Phallales) use odor, and perhaps color, to attract spore dispersing insects. Diptera, in particular, consume a sweet malodorous spore-containing mucous smeared on the fungal surface. Spores develop after being discharged in the insect feces (discussed in Ramsbottom 1953). An early conjecture on the function of fruiting body luminescence was that lights, like odor and color in stinkhorns, lure spore dispersers (Ewart 1906; see also Lloyd 1974, 1977).³

A large proportion of the animals attracted to luminous fungi are potential consumers of its spores. Many Collembola feed on fungal spores, mycelia, and fruiting bodies. Some members of captured Diptera families breed in fungi. The phorid *Megaselia halterata*, for instance, is a pest of cultivated mushrooms (Oldroyd 1964). Whether spores of *D. pusillus* pass unharmed through the insect gut is

²The following functions concern heterospecific receivers; however, bioluminescence is often intimately associated with mating (see Lloyd 1977). Sexual congress in relevant Basidiomycetes consists of exchange of nuclei between haploid mycelia. Is it possible that glows might direct the growth of photo-sensitive hyphae at this stage and so serve as mating signals? Such an explanation fails to account for luminosity in diploid mycelia or the fruiting body.

³Insects may evolve an affinity for fungal lights due to "rewards," in food, shelter, etc., the fungus provides. An alternative is that attraction is due to fungal exploitation of arthropod "phototropisms." The function of "phototropisms" are often obscure. Some are apparently effects of orientation systems based on the relative position of celestial objects (see Lloyd 1977).

unknown. Nor is it known if attracted flies, such as phorids and cecidomyiids, would be useful agents of dispersal. Vagile adults may not feed on fungal materials. Protein consumption by cecidomyiids is particularly rare (see Sivinski and Stowe 1981). Spores may be moved, however, by attachment to the surface of a passing insect.

The topography and timing of luminous displays are often suggestive of guiding dispersers. In *Mycena pruinosa-viscida* and *M. rorida* from the Far Eastern tropics only the spores emit light (Haneda 1955). Most fruiting body lights are restricted to, or brighter in, the spore bearing hymenium (Wassink 1978) and *Panellus stypticus* glows most strongly at the time of spore maturation (Buller 1924). Conscriptio of dispersal agents is less likely to account for light-emitting mycelia, unless mycelial cells pass safely through the gut or can be carried to new locations on an arthropod's exoskeleton.

Attraction of carnivores: Predaceous arthropods were found on glowing traps in numbers that border on significance, and fungus/predator interactions can be imagined as important in the evolution of bioluminescence. Luminous fungi might concentrate carnivores about them by exploiting their "phototropisms." If predators arrive at rates effectively greater than lured fungivores, the resulting predator:prey ratio may favor the fungus (an argument similar to but more evolutionarily feasible than the "burglar alarm" theory of Dinoflagellate luminescence; Burkenroad 1943; see Buck 1978). Such an advantageous ratio is not obvious in my sample. Alternatively, carnivores could seek out luminous fungi as locales of high prey density. Glowing mushrooms might be mistaken for luminescent animal prey.

Attraction of fungivores: If luminous mycelia are unpalatable, or otherwise difficult to ingest, then fungivores attracted to lights might consume adjacent competitors.

Attraction of fertilizers: Lloyd (1974) suggests that arthropods lured by luminescent fungus might excrete beneficial materials and so aid growth. Any nutritional gain must be balanced by the metabolic expense of the signal.

Repulsion of negatively phototropic fungivores: Bioluminescence might repel an organism's negatively phototropic enemies or competitors (Nicol 1962; see also Sivinski 1981 and citations). Repulsion is particularly plausible in explaining luminous mycelia, some of

which occur buried in litter, inside rotting logs, or on roots deep underground where the opacity of the environment precludes attraction as a function of light.

Among surface dwelling arthropods, there is no indication of a light-avoiding taxon. This does not preclude repulsion. A rare, but dangerous, enemy could keep fungal lights burning but escape inclusion in the present sample, especially since mycelia baited traps were not placed in the area of greatest mycelial abundance, deep in the leaf litter. The intended receiver may not be an arthropod or even macroscopic. Protozoa sometimes respond to lights. A glow could repel certain pathogens and keep the fungus free of particular diseases.

Light as a warning signal: Lights emitted by unpalatable fungi might serve as warning signals directed towards nocturnal fungivores (a similar function has been hypothesized for ancestral flowers, Hinton 1973). Of North American fungi with luminous fruiting bodies, one, *P. stypticus*, is a bitter tasting purgative, while another, *Omphalotus olearius*, is a toxic hallucinogen (Miller 1979; the palatability of *D. pusillus* is unknown). *Pleurotus japonicus*, a luminescent Japanese species, is deadly poisonous (Buller 1924). However, the luminous fruiting bodies of Malaysian *Mycena manipularis* are quickly attacked by fungus gnats (Corner 1954; gnats could be specialists, immune to toxins). Again there is no evidence of arthropods avoiding fungal lights. My traps, of course, would fail to quantify the discouragement of deer or other large fungivores.

Like aposematic insects, luminous mushrooms often occur in clumps (kin groups?) (see illustrations in Buller 1924, Harvey 1957; also descriptions in Wassink 1978). Aggregations might intensify warning signals (Cott 1957) and be instrumental in the evolution of conspicuousness (Fisher 1930, for arguments concerning the kin selection of aposematism). Several tropical light emitters, however, apparently occur singly (see Wassink 1978).

White fungi can reflect enough celestial light to be surprisingly obvious at night (noticed at twilight by Lloyd 1977). An assumption of similar receivers for the bright white and luminous signals of fruiting bodies allows the nocturnal aposematic signal hypothesis to be tested with a larger sample. Mushrooms that appear to me to be uniformly bright white include 6 toxic species, 13 edible and 5 whose

palatability is unknown (color and palatabilities from photos and text of Miller 1979). This distribution does not support the aposematism argument (in comparison with a random sample of 41 non-poisonous and 9 poisonous species $\chi^2 = 0.80$ $p > .25$).

SUMMARY

Arthropods, principally Collembola and Diptera, are attracted to the lights of luminous fungal mycelia (*Mycena sp.*) and fruiting bodies (*Dictyopanus pusillus*). Such attraction does not prove that bioluminescence has evolved to lure insects but does affect the plausibility of hypotheses concerning the function of fungal glows. The possibilities of lights being used to lure spore dispersers, attract consumers of fungivores and competing fungi, repel negatively phototropic fungivores, and serve as warning signals, are discussed.

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LITERATURE CITED

- BUCK, J.
1978. Functions and evolutions of bioluminescence. Pages 419-460 in P. J. Herring (ed.). *Bioluminescence in action*. Academic Press, New York.
- BULLER, A. H.
1924. The bioluminescence of *Panus stypticus*. *Researches on fungi*. Vol. 3. pp. 357-431.
- BURKENROAD, M. D.
1943. A possible function of bioluminescence. *J. Mar. Res.* 5: 161-164.
- CORNER, E. J. H.
1974. Further descriptions of luminous agarics. *Trans. Br. Mycol. Soc.* 37: 256-271.
- COTT, H. B.
1957. *Adaptive coloration in animals*. Methuen and Co., Inc., London.
- EWART, A. J.
1906. Note on the phosphorescence of *Agaricus (Pleurotus) candescens*. *Bull. Vict. Nat.* 23: 174.
- FISHER, R. A.
1930. *The genetical theory of natural selection*. Oxford Univ. Press, London.

- HANEDA, Y.
1955. Luminous organisms of Japan and the Far East. Pages 335-386 in F. H. Johnson (ed.). *The luminescence of biological systems*. Am. Assoc. Adv. Sci., Wash., D. C.
- HARVEY, E. N.
1952. *Bioluminescence*. Academic Press, New York.
- HINTON, H. E.
1973. Natural deception. Pages 96-159 in R. L. Gregory and E. H. H. Gombrich (eds.). *Illusion in nature and art*. Charles Scribner's Sons, New York.
- LLOYD, J. E.
1974. Bioluminescent communication between fungi and insects. *Fla. Entomol.* 57: 90
1977. Bioluminescence and communication. Pages 164-183 in T. A. Sebeok (ed.). *How animals communicate*. Ind. Univ. Press, Bloomington, Ind.
- MILLER, O. K., JR.
1979. *Mushrooms of North America*. E. P. Dutton, New York, N. Y.
- NICOL, J. A. C.
1962. Animal luminescence. *Adv. Comp. Physiol. Biochem.* 1: 217-273.
- OLDROYD, H.
1964. *The natural history of flies*. W. W. Norton and Co., Inc., New York.
- PROSSER, C. L., AND F. A. BROWN, JR.
1961. *Comparative animal physiology*. W. B. Saunders Co., Philadelphia, Pa.
- RAMSBOTTOM, J.
1953. *Mushrooms and toadstools*. Collins, London.
- SIVINSKI, J.
1981. The nature and possible functions of bioluminescence in Coleoptera larvae. *Coleopt. Bull.* (in press)
1982. Prey attraction by luminous larvae of the fungus gnat *Orfelia fultoni*. (submitted)
- SIVINSKI, J., AND M. STOWE.
1981. A kleptoparasitic cecidomyiid and other flies associated with spiders. *Psyche*. 87: 337-348.
- WASSINK, E. C.
1978. Luminescence in fungi. Pages 171-197 in P. J. Herring (ed.). *Bioluminescence in action*. Academic Press, New York.
- ZAHL, P. A.
1971. The secrets of nature's night lights. *Natl. Geogr.* 140: 45-70.